

# UNITED STATES PATENT APPLICATION

TITLE:

METHOD AND SYSTEM FOR AIRCRAFT FLOW MANAGEMENT

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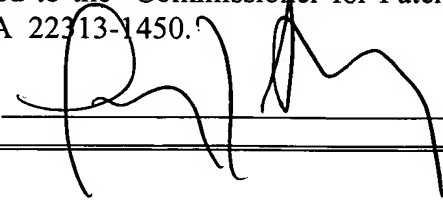
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METHOD AND SYSTEM FOR AIRCRAFT FLOW MANAGEMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 60/458,027, entitled "Method And System For Aircraft Flow Management By Airline/Aviation Authorities," filed March 25, 2003 by R. Michael Baiada and Lonnie H. Bowlin.

This application is related to the following U.S. Patent Documents: Provisional Patent Application No. 60/332,614, entitled "Method And System For Allocating Aircraft Arrival/Departure Slot Times," filed November 19, 2001; Regular Patent Application No. 10/299,640, entitled "Method And System For Allocating Aircraft Arrival/Departure Slot Times," filed November 19, 2002; U.S. Patent No. (USPN) 6,463,383, issued 10/8/02 and entitled "Method And System For Aircraft Flow Management By Airlines/Aviation Authorities;" Provisional Application No. 60/129,563, entitled "Tactical Aircraft Management," filed April 16, 1999; Regular Patent Application No. 09/549074, entitled "Tactical Airline Management," filed April 16, 2000; Regular Patent Application No. 10/238,032, entitled "Method and System For Tracking and Prediction of Aircraft Trajectories," filed 9/6/02; and Provisional Patent Application No. 60/493,494, entitled "Method and System For Tactical Gate Management By Airlines, Airport and Aviation Authorities," filed 8/8/03; all these applications and patents having been submitted by the same applicants: R. Michael Baiada and Lonnie H. Bowlin. The teachings of these materials are incorporated herein by reference to the extent that they do not conflict with the teaching herein.

## BACKGROUND OF THE INVENTION

### 1. FIELD OF THE INVENTION

The present invention relates to vehicle navigation and flow management. More particularly, this invention relates to methods and systems for airlines or aviation/airport authorities to better manage the flow of a plurality of aircraft into and out of a system or set of system resources.

### 2. DESCRIPTION OF THE RELATED ART

The need for and advantages of management operation systems that optimize complex, multi-faceted processes have long been recognized. Thus, many complex methods and optimization systems have been developed. However, as applied to management of the aviation industry, such methods often have been fragmentary or overly restrictive and have not addressed the overall optimization of key aspects of an aviation authority's regulatory function, such as the flow of a plurality of arrival/departure aircraft to/from a system resource or set of system resources.

The patent literature for the aviation industry's operating systems and methods includes: USPN 6,463,383, issued 10/8/02 to the present applicants and entitled "Method And System For Aircraft Flow Management By Aviation Authorities;" USPN 5,200,901, issued 4/6/93 to Gerstenfeld and entitled "Direct Entry Air Traffic Control System for Accident Analysis and Training;" USPN 4,196,474, issued 4/1/80 to Buchanan & Kiley and entitled "Information Display Method and Apparatus for Air Traffic Control;" United Kingdom Patent No. 2,327,517A – "Runway Reservation System," and PCT International Publication No. WO 00/62234 – "Air Traffic Management System."

Aviation regulatory authorities (e.g., various Civil Aviation Authorities (CAA) throughout the world, including the Federal Aviation Administration (FAA) within the U.S.) are responsible for matters such as the separation of in-flight aircraft. In an attempt to optimize their regulation of this activity, most CAAs have chosen to

1 segment this activity into various phases (e.g., taxi separation, takeoff runway  
2 assignment, enroute separation, oceanic separation, arrival/departure sequencing and  
3 arrival/departure runway assignment) which are often sought to be independently  
4 optimized.

5 These optimizations are usually attempted by various, independent ATC  
6 controllers. Unfortunately, this situation often appears to result in optimization  
7 actions by individual parts of the airspace system (e.g., individual controllers or  
8 pilots) which have the effect of reducing the aviation industry's overall safety and  
9 efficiency.

10 There appears to have been few successful attempts by the various  
11 airlines/CAAs/airports to make real-time, trade-offs between their different segments  
12 and the competing goals of these segments as it relates to optimizing the safe and  
13 efficient movement and flow of aircraft. For example, in the sequencing of the  
14 arrival/departure flow of aircraft to an airport, it often happens that some sequencing  
15 actions are taken too early (e.g., ground holds on aircraft before enough data is  
16 available to determine the validity of an apparent constraint in the arrival flow at the  
17 destination airport; see PCT International Publication No. WO 00/62234 – “Air  
18 Traffic Management System”) or too late (e.g., when an aircraft is within 50 to 100  
19 miles from an airport) to resolve a problem.

20 To better understand these aviation processes, FIG. 1 has been provided to  
21 indicate the various segments in a typical aircraft flight process. It begins with the  
22 filing of a flight plan by the airline/pilot with a CAA. Next the pilot arrives at the  
23 airport, starts the engine, taxis, takes off, flies the flight plan (i.e., route of flight),  
24 lands and taxis to parking. At each stage during the movement of the aircraft on an  
25 IFR flight plan, the CAA's Air Traffic Control (ATC) system must approve any  
26 change to the trajectory of the aircraft. Further, anytime an aircraft on an IFR flight  
27 plan is moving, an ATC controller is responsible for ensuring that an adequate  
28 separation from other IFR aircraft is maintained. During the last part of a flight,  
29 initial arrival sequencing (accomplished on a first come, first serve basis, e.g., the  
30 aircraft closest to the arrival fix is first, next closest is second and so on) is  
31 accomplished by the enroute ATC center near the arrival/departure airport (within

1 approximately 100 miles of the airport), refined by the arrival/departure ATC facility  
2 (within approximately 25 miles of the arrival airport), and then approved for landing  
3 by the arrival ATC tower (within approximately 5 miles of the arrival airport).

4 For example, current CAA practices for managing arrivals at destination  
5 airports involve sequencing aircraft arrivals by linearizing an airport's traffic flow  
6 according to very structured, three-dimensional, aircraft arrival paths, 100 to 200  
7 miles from the airport or by holding incoming aircraft at their departure airports. For  
8 a large hub airport (e.g., Chicago, Dallas, Atlanta), these paths involve specific  
9 geographic points that are separated by approximately ninety degrees; see FIG. 2.  
10 Further, if the traffic into an arrival fix for an airport is relatively continuous over a  
11 period of time, the linearization of the aircraft flow is effectively completed hundreds  
12 of miles from the arrival fix. This can significantly restrict all the aircraft's arrival  
13 speeds, since all in the line of arriving aircraft are limited to that of the slowest  
14 aircraft in the line ahead.

15 Unfortunately, if nature adds a twenty-mile line of thunderstorms over one of  
16 the structured arrival fixes - the flow of traffic stops. Can the aircraft easily fly  
17 around the weather? Many times - yes. Will the structure in the current ATC system  
18 allow it? No. To fly around the weather, an arriving aircraft could potentially  
19 conflict with the departing aircraft which the system dictates must climb out from the  
20 airport between the arrival fixes.

21 The temporal variations in the flow of aircraft into an airport can be quite  
22 significant. FIG. 3 shows for the Dallas-Ft. Worth Airport the times of arrival at the  
23 airport's runways for the aircraft arriving during the thirty minute time period from  
24 22:01 to 22:30. It can be seen that the numbers of aircraft arriving during the  
25 consecutive, five-minute intervals during this period were 12, 13, 6, 8, 6 and 5,  
26 respectively. While some of these variations are due to the aircraft's planned  
27 scheduling differences, much of it is also seen to be due to the many decisions,  
28 independent in nature, that impact whether a scheduled flight will arrive at its fix  
29 point at its scheduled time. These decisions may include whether a customer service  
30 agent shuts a departing aircraft's door at the scheduled time or maybe waits for some  
31 late, connecting passengers, or the personal preferences that the pilots exhibit in

1 setting their flight speeds for the various legs of their flights. These types of  
2 independent decisions lead to a random distribution of the arrival aircraft, regardless  
3 of the schedule, and obviously affect the outcome of the arrival flow. This type of  
4 random arrival pattern leads to random spacing of the arrival aircraft as they approach  
5 a runway, which leads to wasted capacity.

6 Much of the current thinking concerning the airline/ATC delay problem is that  
7 it stems from the over scheduling by the airlines of too many aircraft into too few  
8 runways. While this may be true in part, it is also the case that the many apparently  
9 independent decisions that are made by an airline's staff and various ATC controllers  
10 may significantly contribute to airline/ATC delay/congestion problems.

11 These independent actions for each of the arriving flights, without regard to  
12 system effects, lead to a variance in the arrival flow, thus assuring a random outcome  
13 as the aircraft approach a destination airport. Mitigating the variance to reduce  
14 randomness and queuing represents a unique aspect of the present invention.

15 For illustrative purposes, one can compare the aircraft arrival flow into a busy  
16 airport to the actions of grade school children at the end of class. When the dismissal  
17 bell rings, if all of the students rush to the door, fighting to be the first one out, the  
18 throughput of the door is lowered. Conversely, if the students file out in an orderly  
19 and sequenced fashion, the actual throughput of the door is higher. In either case, the  
20 capacity of the door is the same, but by managing the flow through the door, the  
21 door's effective throughput is higher. The same can be said for an airport.

22 The explanation of the effects of randomness can be found in the mathematics  
23 of queue theory, which states that as the demand approaches capacity the queue  
24 waiting time increases at a rate proportional to the inverse of the difference between  
25 demand and capacity.

26 These delays are especially problematic since they are seen to be cumulative.  
27 FIG. 4 shows, for all airlines and a number of U.S. airports, the percentage of aircraft  
28 arriving on time during various one hour periods throughout a typical day. This on  
29 time arrival performance is seen to deteriorate throughout the day.

30 Where there are problems with over scheduling, the optimal, real-time  
31 sequencing of the various sizes of incoming aircraft could conceivably offer a

possible mechanism for remedying such problems. For example, the consistent flow of aircraft at the runway end can increase effective capacity. Further, current aviation authority rules require different spacing between aircraft based on the size of the aircraft. Typical spacing between the arrivals of aircraft of the same size is three miles, or approximately one minute based on normal approach speeds. But if a small (Learjet, Cessna 172) or medium size aircraft (B737, MD80) is behind a large aircraft (B747, B767), this spacing distance is stretched out to five miles or one and a half to two minutes for safety considerations.

Thus, it can be seen that if a sequence of ten aircraft is such that a large aircraft alternates every other one with a small aircraft, the total distance of the arrival sequence of aircraft to the runway ( $5 + 3 + 5 + 3 + 5 + 3 + 5 + 3 + 5 + 3$ ) is 40 miles. But if this sequence can be altered to put all of the small aircraft in positions 1 through 5, and all of the very large aircraft in slots 6 through 10, the total distance of the arrival sequence of aircraft to the runway is only 30 miles, since the spacing between the aircraft is consistently 3 miles. If the sequence is altered to the second scenario, the ten aircraft can land in a shorter period of time, thus freeing up additional landing slots behind this group of ten aircraft.

Unfortunately, to correct over capacity problems in the current art, the controller only has one option. They take the first over-capacity aircraft that arrives at the airport and move it backward in time. The second such aircraft is moved further back in time, the third, even further back, etc. Without a process in the current art to move aircraft forward in time or manage the arrival sequence in real time, the controller has only one option – delay the arrivals.

The current art of aircraft flow sequencing (to assure proper aircraft separation) to an airport can be broken down into seven distinct tools used by air traffic controllers, as applied in a first come, first serve basis, include:

1. Structured DogLeg Arrival Routes – The structured routings into an arrival fix are typically designed with doglegs. The design of the dogleg is two straight segments joined by an angle of less than 180 degrees. The purpose of the dogleg is to allow controllers to cut the corner as necessary to maintain the correct spacing between arrival aircraft.

1           2. Vectoring and Speed Control – If the actual spacing is more or less than the  
2           desired spacing, the controller can alter the speed of the aircraft to correct the spacing.  
3           Additionally, if the spacing is significantly smaller than desired, the controller can  
4           vector (turn) the aircraft off the route momentarily to increase the spacing. Given the  
5           last minute nature of these actions (within 100 mile of the airport), the outcome of  
6           such actions is limited.

7           3. The Approach Trombone - If too many aircraft arrive at a particular airport  
8           in a given period of time, the distance between the runway and base leg can be  
9           increased; see FIG. 5. This effectively lengthens the final approach and downwind  
10          legs allowing the controller to “store” or warehouse in-flight aircraft. A problem with  
11          this approach is that as the number of aircraft increases, the controller is required to  
12          handle more and more aircraft, such that his/her communication requirements also  
13          increase. The effect of such an increase is that while talking to one aircraft, the  
14          controller’s instruction to another aircraft to turn towards the final approach is  
15          delayed slightly, which increases the spacing between aircraft on final approach and  
16          landing. Even a delay of ten seconds on such a call increases the spacing between  
17          such aircraft by approximately one mile. Three such delayed calls and a runway  
18          landing slot is missed. As was described above, the runway capacity remained  
19          unchanged, but its throughput was decreased.

20          4. Miles in Trail – If the approach trombone can’t handle the over demand for  
21          the runway asset, the ATC system begins spreading out the arrival/departure flow  
22          linearly. It does this by implementing “miles-in-trail” restrictions. Effectively, as the  
23          aircraft approach the airport for landing, instead of 5 to 10 miles between aircraft on  
24          the linear arrival/departure path, the controllers begin spacing the aircraft at 20 or  
25          more miles in trail, one behind the other; see FIG. 6.

26          5. Ground Holds – If the separation authorities anticipate that the approach  
27          trombone and the miles-in-trail methods will not hold the aircraft overload, aircraft  
28          are held at their departure point and metered into the system using assigned takeoff  
29          times.

30          6. Holding – If events happen too quickly, the controllers are forced to use  
31          airborne holding. Although this can be done anywhere in the system, this is usually



1 done at one of the arrival fixes to an airport. Aircraft enter the “holding stack” from  
2 the enroute airspace at the top; see FIG. 7. Each holding pattern is approximately 10  
3 to 20 miles long and 3 to 5 miles wide. As aircraft exit the bottom of the stack  
4 towards the airport, aircraft orbiting above are moved down 1,000 feet to the next  
5 level.

6 7. Reroute – If a section of airspace, enroute center, or airport is projected to  
7 become overloaded, the aviation authority occasionally reroutes individual aircraft  
8 over a longer lateral route to delay the aircraft’s entry to the predicted congestion.

9 CAA’s current air traffic handling procedures are seen to result in significant  
10 inefficiencies. For example, pilots routinely mitigate some of the assigned ground  
11 hold or reroute orders by increasing the aircraft’s speed during its flight, which often  
12 yields significantly increased fuel expenses. Also, vectoring and speed control by the  
13 ATC controller are usually accompanied with descents to a common altitude which  
14 may often be far below the aircraft’s optimum cruise altitude, again with the use of  
15 considerable extra fuel. Further, the manual aspects of the sequencing and arrival  
16 ATC tasks can result in significantly greater separations between aircraft than are  
17 warranted; thereby significantly reducing an airport’s landing capacity.

18 Thus, despite the above noted prior art, airlines/CAAs/airports continue to  
19 need safer and more efficient methods and systems to better manage the  
20 arrival/departure flow of a plurality of aircraft into and out of a system resource, like  
21 an airport, or a set of system resources, so as to yield increased aviation safety and  
22 airline/airport/airspace operating efficiency.

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### 3. OBJECTS AND ADVANTAGES

There has been summarized above, rather broadly, the prior art that is related to the present invention in order that the context of the present invention may be better understood and appreciated. In this regard, it is instructive to also consider the objects and advantages of the present invention.

It is an object of the present invention to provide a method and system which allows an aviation system (e.g., an airline, airport or CAA) to better achieve its specified safety and operational efficiency goals with respect to the arrival and departure of a plurality of aircraft at a specified system resource, like an airport, or set of resources, thereby overcoming the limitations of the prior art described above.

It is another object of the present invention to present a method and system for the real time management of aircraft that takes into consideration a wider array of real time parameters and factors that heretofore were not considered. For example, such parameters and factors may include: aircraft related factors (i.e., speed, fuel, altitude, route, turbulence, winds, and weather) and ground services and common asset availability (i.e., runways, airspace, Air Traffic Control (ATC) services).

It is another object of the present invention to provide a method and system that will enable the airspace users to increase their safety and efficiency of operation.

It is yet another object of the present invention to provide a method and system that will allow an airport or other system resource to enhance its overall operating efficiency, even at the possible expense of its individual components that may become temporarily less effective. After the system's overall operation is optimized, then, as a secondary task, the present invention tries to enhance the efficiency of the individual components (i.e., meets a specific airline's business needs if provided) as long as they do not degrade the overall, optimized solution.

It is a further object of the present invention to provide a method and system that analyzes numerous real time information and other factors simultaneously, identifies system constraints and problems as early as possible, determines alternative

possible trajectory sets, chooses the better of the evaluated asset trajectory sets, implements the new solution, and continuously monitors the outcome.

It is still a further object of the present invention to temporally manage the flow of aircraft into or out of a specific system resource in real time to prevent that resource from becoming overloaded. Further, if the outcome of prior events puts demand for that system resource above capacity, it is then the object of the present invention to maximize the throughput of the now constrained system resource with a consistent, more optimally sequenced flow of aircraft to/from that system resource.

It is an additional object of the present invention to minimize the large temporal variations to arrival/departure flows so as to mitigate the effects of randomness and queuing.

Such objects are different from the current art, which manages aircraft into or out of a specific resource linearly using distance based processes, or limits access to the entire system, not just the specific constrained system resource.

These and other objects and advantages of the present invention will become readily apparent as the invention is better understood by reference to the accompanying summary, drawings and the detailed description that follows.

## SUMMARY OF THE INVENTION

The present invention is generally directed towards mitigating the limitations and problems identified with prior methods used by CAAs to manage their air traffic control function. Specifically, the present invention is designed to maximize the throughput of all aviation system resources, while limiting, or eliminating completely ground holds, reroutes, doglegs and vectoring by CAAs.

In accordance with one preferred embodiment of the present invention, a method for managing the flow of a plurality of aircraft at an aviation resource, based upon specified data and operational goals pertaining to the aircraft and resource and the control of aircraft arrival fix times at the resource by a system manager charged with managing the resource, includes the steps of: (a) collecting and storing the specified data and operational goals, (b) processing the specified data to predict an initial arrival fix time for each of the aircraft at the resource, (c) specifying a goal function which is defined in terms of arrival fix times and whose value is a measure of how well the aircraft meet the operational goals based on achieving specified arrival fix times, (d) computing an initial value of the goal function using the predicted initial arrival fix times, (e) utilizing the goal function to identify potential arrival fix times to which the arrival fix times can be changed so as to result in the value of the goal function indicating a higher degree of attainment of the operational goals than that indicated by the initial value of the goal function, (f) if the utilization step yields a goal function whose value is higher than the initial goal function value, defining requested arrival fix times to be those arrival fix times associated with the higher goal function value; but, if the utilization step does not yield a goal function whose value is higher than the initial goal function value, defining requested arrival fix times to be the predicted, initial arrival fix times, (g) communicating the requested arrival fix times to the system manager to determine whether authorization may be obtained from the system manager for the aircraft to use the requested arrival fix times, (h) if the arrival fix times authorization is obtained, establishing the requested arrival fix times as the targeted arrival fix times of the aircraft; but, if the arrival fix times authorization is not obtained, continuing to use the goal function to identify potential

1 arrival fix times which can be communicated to the system manager until arrival fix  
2 times authorization is obtained.

3 In accordance with another embodiment of the present invention, this method  
4 further comprises the step of: communicating information about the targeted arrival  
5 fix times to the aircraft so that the aircraft can change their trajectories so as to meet  
6 the targeted arrival fix times, monitoring the ongoing temporal changes in the  
7 specified data and operational goals so as to identify temporally updated specified  
8 data and operational goals, processing the temporally updated specified data to  
9 predict updated arrival fix times, computing an updated value of the goal function  
10 using the updated arrival fix times, assessing the updated goal function value to  
11 determine whether its value and associated updated arrival fix times yield a higher  
12 degree of attainment of the operational goals than used as the basis for the requested  
13 arrival fix times, if the updated goal function value implies a higher degree of  
14 attainment of the operational goals than that used as the basis for the requested arrival  
15 fix times, defining new requested arrival fix times to be the updated arrival fix times,  
16 but if not, utilizing the goal function to identify new, requested arrival fix times to  
17 which the targeted arrival fix times can be changed so as to result in the value of the  
18 goal function indicating a higher degree of attainment of the operational goals than  
19 that indicated by the updated arrival fix times, and communicating the new requested  
20 arrival fix times to the system manager to determine whether authorization may be  
21 obtained from the system manager for the aircraft to use the new requested arrival fix  
22 times as their new targeted, arrival fix times.

23 In accordance with another preferred embodiment of the present invention, a  
24 system, including a processor, memory, display and input device, for an aviation  
25 system to temporally manage the flow of a plurality of aircraft with respect to a  
26 specified system resource, based upon specified data, some of which are temporally  
27 varying, and operational goals pertaining to the aircraft and system resource, is  
28 comprised of the means for achieving each of the process steps listed in the above  
29 methods.

30 Additionally, the present invention can take the form of a computer program  
31 product in a computer readable memory for controlling a processor to allow an

1       aviation system to temporally manage the flow of a plurality of aircraft with respect  
2       to a specified system resource, based upon specified data, some of which are  
3       temporally varying, and operational goals pertaining to the aircraft and system  
4       resource. This computer program product also includes the means for achieving each  
5       of the process steps listed in the above methods.

6               Thus, there has been summarized above, rather broadly, the present invention  
7       in order that the detailed description that follows may be better understood and  
8       appreciated. There are, of course, additional features of the invention that will be  
9       described hereinafter and which will form the subject matter of any eventual claims to  
10      this invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 presents a depiction of a typical aircraft flight process.

FIG. 2 illustrates a typical arrival/departure flow from a busy airport.

FIG. 3 illustrates an arrival bank of aircraft at Dallas/Ft. Worth airport collected as part of NASA's CTAS project.

FIG. 4 illustrates the December 2000, on-time arrival performance at sixteen specific airports for various one hour periods during the day.

FIG. 5 presents a depiction of the arrival/departure trombone method of sequencing aircraft.

FIG. 6 presents a depiction of the miles-in-trail method of sequencing aircraft.

FIG. 7 presents a depiction of the airborne holding method of sequencing aircraft.

FIG. 8 presents a depiction of the preferred method of the present invention for optimizing the control of aircraft approaching a specified airport.

FIG. 9a – 9e provides an illustration of the decision processes required to determine an airport's arrival/departure flow of aircraft.

FIG. 10 illustrates the various types of data that are used in the process of the present invention.

FIG. 11a – 11b illustrates the optimization processing sequence of the present invention.

FIG. 12 illustrates the difference between a random arrival flow of aircraft and a managed arrival flow of aircraft to an arrival fix.

FIG. 13 illustrates an aircraft scheduled arrival versus capacity at a typical hub airport. The graph is broken down into 15-minute blocks of time.

FIG. 14 illustrates a representative Goal Function of the present invention for a single aircraft.

FIG. 15 provides a Table that illustrates the value of a representative Goal Function of the present invention for two aircraft.

FIG. 16 illustrates the data flow for a process to coordinate arrival fix times by multiple operators of the present invention.

1           FIG. 17 illustrates the effects of variance, within an aircraft arrival flow to an  
2 airport, such that as demand nears capacity, queuing, and therefore delays increase.

3           FIG. 18 illustrates the variance of the arrival paths of a typical aircraft arrival  
4 flow to an airport over a twenty-four hour period.

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## DEFINITIONS

ACARS – ARINC Communications Addressing and Reporting System. This is a discreet data link system between the aircraft and the airline. This provides very basic email capability between the aircraft and a limited set of operational data and personnel. Functionality from this data link source includes operational data, weather data, pilot to dispatcher communication, pilot to aviation authority communication, airport data, OOOI data, etc.

Aircraft Situational Data (ASD) – This an acronym for a real time data source (approximately 1 to 5 minute updates) provided by the world’s aviation authorities, including the Federal Aviation Administration, comprising aircraft position and intent for the aircraft flying over the United States and beyond.

Aircraft Trajectory – The movement or usage of an aircraft defined as a position, time (past, present or future). For example, the trajectory of an aircraft is depicted as a position, time and intent.

Airline – a business entity engaged in the transportation of passengers, bags and cargo on an aircraft

Airline Arrival Bank – A component of a hub airline’s operation where numerous aircraft, owned by the hub airline, arrive at a specific airport (hub airport) within a very short time frame.

Airline Departure Bank – A component of hub aviation’s operation where numerous aircraft, owned by the hub aviation, depart at a specific airport (hub airport) within a very short time frame.

Airline Gate – An area or structure where aircraft owners/airlines park their aircraft for the purpose of loading and unloading passengers and cargo.

Air Traffic Control System (ATC) – A system to assure the safe separation of moving aircraft by an aviation regulatory authority. In numerous countries, this system is managed by the Civil Aviation Authority (CAA). In the United States the federal agency responsible for this task is the Federal Aviation Administration (FAA).

1           Arrival fix/Cornerpost – At larger airports, the aviation regulatory authorities  
2 have instituted structured arrivals that bring all arrival/departure aircraft over  
3 geographic points (typically four). These are typically 30 to 50 miles from the  
4 arrival/departure airport and are separated by approximately 90 degrees. The purpose  
5 of these arrival fixes or cornerpost is so that the controllers can better sequence the  
6 aircraft, while keeping them separate from the other arrival/departure aircraft flows.  
7 In the future it may be possible to move these merge points closer to the airport, or  
8 eliminate them all together. As described herein, the arrival fix cornerpost referred to  
9 herein will be one of the points where the aircraft flows merge. Additionally, besides  
10 an airport, as referred to herein, arrival fixes can refer to entry points to any system  
11 resource, e.g., a runway, an airport gate, a section of airspace, a CAA control sector, a  
12 section of the airport ramp, etc. Further, an arrival fix/cornerpost can represent an  
13 arbitrary point in space where an aircraft flow merges at some past, present or future  
14 time.

15           Asset – These include assets such as aircraft, airports, runways, and airspace,  
16 etc.

17           Automatic Dependent Surveillance (ADS) – A data link surveillance system  
18 currently under development. The system, which is installed on the aircraft, captures  
19 the aircraft position from the navigation system and then communicates it to the  
20 CAA/FAA and other aircraft.

21           Aviation Authority – This is the agency responsible for the separation of  
22 aircraft when they are moving. Typically, this is a government-controlled agency, but  
23 a recent trend is to privatize this function. In the US, this agency is the Federal  
24 Aviation Administration (FAA). In numerous other countries, it is referred to as the  
25 Civil Aviation Authority (CAA). As referred to herein, it can also mean an airport  
26 authority which manages the airport

27           Aviation System – As referred to herein, meant to represent an airline, airport,  
28 CAA, FAA or any other organization or system that has or can provide impact on the  
29 flow of a plurality of aircraft into or out of a system resource.

30           Block Time – The time from aircraft gate departure to aircraft gate arrival.  
31 This can be either scheduled block time (schedule departure time to scheduled

1 arrival/departure time as posted in the aviation system schedule) or actual block time  
2 (time from when the aircraft door is closed and the brakes are released at the  
3 departure station until the brakes are set and the door is open at the arrival/departure  
4 station).

5 CAA – Civil Aviation Authority. As used herein is meant to refer to any  
6 aviation authority responsible for the safe separation of moving aircraft.

7 Cooperative Decision-Making (CDM) – A recent program between FAA and  
8 the airlines, wherein the airlines provide the FAA a more realistic schedule of their  
9 aircraft. For example if an airline cancels 20% of its flights into a hub because of bad  
10 weather, it would advise the FAA. In turn, the FAA compiles the data and  
11 redistributes it to all participating members.

12 Common Assets – Assets that must be utilized by all airspace/airport/runway  
13 users and which are usually controlled by the aviation authority (i.e., CAA, FAA,  
14 airport). These assets (i.e., runways, ATC system, airspace, etc.) are not typically  
15 owned by any one airspace user.

16 CTAS – Center Tracon Automation System – This is a NASA developed set  
17 of tools (TMA, FAST, etc.) that seeks to temporally manage the arrival flow of  
18 aircraft from approximately 150 miles from the airport to landing.

19 Federal Aviation Administration – The government agency responsible for the  
20 safe separation of aircraft which are moving in the United States' airspace.

21 Four-dimensional Path – The definition of the movement of an object in one  
22 or more of four dimensions – x, y, z and time.

23 Goal Function – a method or process of measurement of the degree of  
24 attainment for a set of specified goals. As further used herein, a method or process to  
25 evaluate the current scenario against a set of specified goals, generate various  
26 alternative scenarios, with these alternative scenarios, along with the current scenario  
27 then being assessed with the goal attainment assessment process to identify which of  
28 these alternative scenarios will yield the highest degree of attainment for a set of  
29 specified goals. The purpose of the Goal function is to find a solution that “better”  
30 meets the specified goals (as defined by the operators of the present invention, as well  
31 as the aircraft operators) than the present condition and determine if it is worth (as

1 defined by the operator) changing to the “better” condition/solution. This is always  
2 true, whether it is the initial run or one generated by the monitoring system. In the  
3 case of the monitoring system (and this could even be set up for the initial  
4 condition/solution as well), it is triggered by some defined difference (as defined by  
5 the operator) between how well the present condition meets the specified goals versus  
6 some “better” condition/solution found by the present invention. Once the Goal  
7 function finds a “better” condition/solution that it determines is worth changing to,  
8 the present invention translates said “better” condition/solution into some doable task  
9 and then communicates this to the interested parties, and then monitors the new  
10 current condition to determine if any “better” condition/solution can be found and is  
11 worth changing again.

12 Hub Airline - An airline operating strategy whereby passengers from various  
13 cities (spokes) are funneled to an interchange point (hub) and connect to various other  
14 cities. This allows the airlines to capture greater amounts of traffic flows to and from  
15 cities they serve, and offers smaller communities one-stop access to literally hundreds  
16 of nationwide and worldwide destinations.

17 IFR – Instrument Flight Rules. A set of flight rules wherein the pilot files a  
18 flight plan with the aviation authorities responsible for separation safety. Although  
19 this set of flight rules is based on instrument flying (e.g., the pilot references the  
20 aircraft instruments) when the pilot cannot see at night or in the clouds, the weather  
21 and the pilot’s ability to see outside the aircraft are not a determining factors in IFR  
22 flying. When flying on an IFR flight plan, the aviation authority (e.g., ATC  
23 controller) is responsible for the separation of the aircraft when it moves.

24 OOOI – A specific aviation data set of; when the aircraft departs the gate  
25 (Out), takes off (Off), lands (On), and arrives at the gate (In). These times are  
26 typically automatically sent to the airline via the ACARS data link, but could be  
27 collected in any number of ways.

28 PASSUR – A passive surveillance system usually installed at the operations  
29 centers at the hub airport by the hub airline. This device allows the airline’s  
30 operational people on the ground to display the airborne aircraft in the vicinity (up to  
31 approximately 150 miles) of the airport where it is installed.

1           Strategic Management – The use of policy level, long range information  
2 (current time up to “n1” hours into the future, where “n1” is defined by the regulatory  
3 authority, typically 6 to 24 hours) to determine demand and certain choke points in  
4 the airspace system.

5           System Resource – a resource like an airport, runway, gate, ramp area, or  
6 section of airspace, etc, that is used by all aircraft. A constrained system resource is  
7 one where demand for that resource exceeds capacity. This may be an airport with 70  
8 aircraft that want to land in a single hour, with landing capacity of 50 aircraft per  
9 hour. Or it could be an airport with 2 aircraft wanting to land at the same exact time,  
10 with capacity of only 1 landing at a time. Or it could be a hole in a long line of  
11 thunderstorms that many aircraft want to utilize. Additionally, this can represent a  
12 group or set of system resources that can be managed simultaneously. For example,  
13 an arrival cornerpost, runway and gate represent a set of system resources that can be  
14 managed as a combined set of resources to better optimize the flow of aircraft.

15           Tactical Management – The use of real time information (current time up to  
16 “n” minutes into the future, where “n” is defined by the aviation regulatory authority,  
17 typically 0 to 6 hours) to modify future events.

18           Trajectory – See aircraft trajectory and four-dimensional path above.

19           VFR – Visual Flight Rules. A set of flight rules wherein the pilot may or may  
20 not file a flight plan with the aviation authorities responsible for separation safety.  
21 This set of flight rules is based on visual flying (e.g., the pilot references visual cues  
22 outside the aircraft) and the pilot must be able to see and cannot fly in the clouds.  
23 When flying on a VFR flight plan, the pilot is responsible for the separation of the  
24 aircraft when it moves.

25

26

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings wherein are shown preferred embodiments and wherein like reference numerals designate like elements throughout, there is shown in the drawings the decision steps involved in preferred methods of the present invention. These methods effectively manage the temporal flow of a plurality of aircraft arrivals into an aviation system resource or set of resources.

For ease of understanding, the ensuing description is based on managing the temporal flow of a plurality of aircraft arrivals into a single system resource (e.g., an airport) based on arrival fix times or enroute speeds as necessary to meet the target arrival fix times that have been assigned to the various aircraft. These fix times are set based upon consideration of specified data, regarding the capacity of the airport and arrival paths, aircraft positions, aircraft performance, user requirements (if available) and the weather, etc. that has been processed so as to identify that set of arrival fix times which allows the airline flying the aircraft into an airport and/or a CAA controlling the airport to better achieve its specified safety and operational efficiency goals.

As discussed above, the overall goal of the present invention is to increase aviation safety and efficiency through the real time management of aircraft from a system perspective. It is important to note that the present invention is in some ways the combination of several process steps. These processes or steps include:

1. An asset trajectory tracking (i.e., three spatial directions and time) process that looks at the current position and status of all aircraft and other system resource assets,
2. An asset trajectory predicting process that inputs the asset's current position and status into an algorithm which predicts the asset's future position and status for a given specifiable time or a given specifiable position,
3. A goal attainment assessment process that assesses at any given instant, based on the inputted position and status of these assets, the degree of attainment of

- 1 the system resource's and aircraft's specified safety and operational efficiency  
2 goals,
- 3 4. An alternative trajectory scenario generation process that generates various  
4 alternative trajectories for the set of aircraft arriving and departing at the  
5 control airport (or other system resource); with these alternative scenarios then  
6 being assessed with the goal attainment assessment process to identify which  
7 of these alternative scenarios will yield the highest degree of attainment (i.e.,  
8 better optimized) of the aviation authority's and aircraft's goals,
- 9 5. A process for translating these alternative trajectories into a new set of targeted  
10 arrival fix times or enroute speeds as necessary to meet the target arrival fix  
11 times for the aircraft,
- 12 6. An optional validation and approval process which entails an airline/CAA or  
13 other system operator validating the practicality and feasibility of assigning the  
14 new set of optimized arrival fix times or enroute speed as necessary to meet the  
15 target arrival fix times to the set of arriving aircraft, then approving the  
16 assignment of these new, arrival fix times to the effected aircraft,
- 17 7. A coordination process (FIG. 16), as necessary, such that operators of the  
18 present invention can communicate their aircraft's arrival fix time requests  
19 (i.e., government agency, system, or process, see Regular Patent Application  
20 filed November 19, 2002, titled, "Method And System For Allocating Aircraft  
21 Arrival/Departure Slot Times", with a Serial #10/299,640) so that such  
22 requested arrival fix times can be evaluated in terms of a greater System Goal  
23 Function which measures the impact that such arrival fix times would have  
24 upon attainment of a greater System Goal/s; wherein, such arrival fixed times  
25 can be modified by negotiation/assignment for the greater good of attainment  
26 of a greater System Goal/s.
- 27 8. A communication process which involves an airline/CAA, other system  
28 operator or automated process communicating these new arrival, fix times to  
29 the effected aircraft,
- 30 9. A closed loop monitoring process, which involves continually monitoring the  
31 current state of these assets. This monitoring process measures the current

1 state of the assets against system capacity and their ability to meet the new  
2 assigned arrival fix times. If at anytime the actions or change in status of one  
3 of the aircraft or other system resource assets would preclude the meeting of  
4 the arrival fix times, or the measurement of the attainment of the current  
5 system solution drops below a specified value, the airline/CAA or other system  
6 operator can be notified, or the system can automatically be triggered, at which  
7 time the search for better, alternative scenarios can be renewed.

8 FIG. 8 provides a flow diagram that represents the decision steps involved in  
9 the control of the aircraft approaching an airport whose operations are sought to be  
10 optimized. It denotes (step 801) how it must first be determined if the aircraft are  
11 sequenced safely and efficiently. In step 802, this method is seen to evaluate all of  
12 the trajectories of the aircraft to determine if temporal changes to these trajectories  
13 would yield a solution where a safer, more efficient sequence of arrival times can be  
14 found. If this cannot be done, this method involves then jumping to step 805.

15 If temporal modifications to the trajectories of the aircraft can produce a better  
16 match to a safer, more efficient arrival/departure sequence, the cost of these changes  
17 must be compared to the benefit produced (step 803). If the cost does not justify the  
18 changes to the trajectory, the process must default to step 805 once again.

19 Conversely, if the cost of modifications to one or more of the trajectories of  
20 the aircraft is lower then the benefit produced, the method then entails, with the  
21 approval of the airline/CAA or other system operator, if required, communicating the  
22 new trajectory goals to the individual aircraft (step 804).

23 Finally, the method involves monitoring the assets to determine if each of the  
24 aircraft will meet their current/new trajectory goal (step 806). This method  
25 continuously analyzes aircraft from present time up to “n” hours into the future,  
26 where “n” is defined by the airline/CAA. The overall time frame for each analysis is  
27 typically twenty-four hours, with this method analyzing the hub arrival/departure  
28 bank at least three to five hours into the future and then continuously monitoring the  
29 aircraft as they proceed to approach the airport.

30 This method is seen to avoid the pitfall of sub-optimizing particular  
31 parameters. It accomplishes this by assigning weighted values to various factors that



1 comprise the airline/CAA's/airport's safety and operational goals. While the present  
2 invention is capable of providing a linear (i.e., aircraft by aircraft optimization)  
3 solution to the optimized control of a plurality of aircraft approaching an airport, it is  
4 recognized that a multi-dimensional (i.e., optimize for the whole set of aircraft,  
5 airport assets, system resources, etc.) solution provides a better, safer and more  
6 efficient solution for the total operation of the airport, including all aspects of the  
7 arrival/departure flow. For the sake of brevity, only the aircraft movement aspects  
8 into an airport are described herein in detail. It should be understood that the present  
9 invention works as well with the flow of aircraft into or out of any aviation system  
10 resource (e.g., airspace, runways, gates, ramps, etc.).

11 Since the implementation of the method of the present invention uses a multi-  
12 dimensional solution that evaluates numerous parameters simultaneously, the  
13 standard, yes-no flow chart is difficult to construct for the present invention.  
14 Therefore, a decision table has been included as FIG. 9a – 9e to better depict the  
15 implementation of the present invention.

16 Decisions 1 and 2 (FIG. 9b – 9c) are seen to involve a number of  
17 airline/user/pilot defined parameters that contribute to determining an aircraft's  
18 optimal arrival/departure time. Since it would be difficult for a CAA/airport to  
19 collect the necessary data to make these decisions, one embodiment of the present  
20 invention leaves these decisions to the airline/user/pilot. That said, it would then be  
21 incumbent on the airline/user/pilot to coordinate their requirements to the  
22 CAA/airport so that they can be used to develop an overall optimization of the flow  
23 of a plurality of aircraft traffic into an airport.

24 In Decision 1 (FIG. 9b), and initially ignoring other possibly interfering  
25 factors such as the weather, other aircraft's trajectories, external constraints to an  
26 aircraft's trajectory, etc., upwards of twenty aircraft parameters must be balanced  
27 simultaneously to optimize the overall performance of each aircraft. This is quite  
28 different than current business practices within the aviation industry, which includes  
29 focusing decision making on a very limited data set (i.e., scheduled on-time arrival,  
30 and possibly one other parameter – fuel burn, if any at all).

1           In Decision 2 (FIG. 9c), an airline's local facilities at the destination airport  
2           are evaluated for their ability to meet the needs and/or wants of the individual aircraft,  
3           while also considering their possible interactions with the other aircraft that are  
4           approaching the same airport. These requirements of the airline/user/pilot must then  
5           be communicated to the CAA/airport.

6           The use of this communicated information and other data (e.g., airport's  
7           resource data, weather, and other data compiled by the aviation authority) in the  
8           Decision 3 (FIG. 9d) phase of this process is the primary area of focus of the current  
9           invention. Here, the user of the present invention focuses on  
10          airspace/runway/arrival/departure capacity and assigns coordinated, arrival fix times  
11          so as to meet the airport's specified safety and operational efficiency goals.

12          For hub airports, this can be a daunting task as thirty to sixty of a single  
13          airline's aircraft (along with numerous aircraft from other airlines) are scheduled to  
14          arrive at the hub airport in a very short period of time. The aircraft then exchange  
15          passengers are serviced and then take off again. The departing aircraft are also  
16          scheduled to takeoff in a very short period of time. Typical hub operations are one to  
17          one and a half hours in duration and are repeated eight to twelve times per day.

18          And finally, in the Airline/Aviation Authority Control Action 1 process (FIG.  
19          9e), the target cornerpost times are transmitted to the aircraft and other interested  
20          parties.

21          FIG. 10 illustrates the various types of data sets that are used in this decision  
22          making process, these include: air traffic control objectives, generalized surveillance,  
23          aircraft kinematics, communication and messages, airspace structure, airspace and  
24          runway availability, user requirements (if available), labor resources, aircraft  
25          characteristics, arrival/departure and departure times, weather, gate availability,  
26          maintenance, other assets, and safety, operational and efficiency goals.

27          FIGS. 11A-11B illustrate the optimization processing sequence of the present  
28          invention. In step 1101A, a set of aircraft is selected whose safe and efficient  
29          operation into a specified airport, during a specified "time window," is sought to be  
30          optimized. The "time window" usually refers to the "arrival bank" of aircraft into the  
31          specified airport. The aircraft from outside this window are not submitted for

1 optimization in this scheduling process, but they are taken into account as far as they  
2 may impose some limitations on those who are in the selected set of aircraft.

3 In step 1102A, the positions and future movement plans for all of the aircraft,  
4 including their predicted arrival fix times, are identified with input from databases  
5 which include Automatic Dependent Surveillance (ADS), FAA's Aircraft Situational  
6 Data (ASD), those of the airlines (if available) and any other information (e.g.,  
7 weather) available as to the position and intent of the aircraft. This calculation of the  
8 future movements for the selected set of aircraft can be computed using an assortment  
9 of relatively standard software programs (e.g., "Aeralib," from Aerospace  
10 Engineering & Associates, Landover, MD and/or Attila, Patent Pending #09/549074,  
11 from ATH Group) with inputted information for each aircraft that includes  
12 information such as filed flight plan, current position, altitude and speed, data  
13 supplied from the airline/user/pilot, etc.

14 In step 1103A, these predicted arrival fix times for the aircraft in the set are  
15 used to compute the value of a "goal" function which is a measure of how well this  
16 set of aircraft will meet their safety and operational goals if they achieve the predicted  
17 arrival fix times. This goal function can be defined in many ways. However, a  
18 preferred method is to define it as the sum of the weighted components of the various  
19 factors or parameters that are used to measure an aircraft's and/or runway's  
20 operational performance (e.g., factors such as: utilizing all of the runway capacity,  
21 difference between scheduled and actual arrival time, fuel efficiency for the flight,  
22 landing at a time when the aircraft can be expeditiously unloaded and serviced).

23 In step 1104A, this goal function is optimized with respect to these predicted  
24 arrival times by identifying potential changes in these predicted arrival times so as to  
25 increase the value of the overall solution as determined by the goal function. The  
26 solution space in which this search is conducted has requirements placed upon it  
27 which ensure that all of its potential solutions are operational. These requirements  
28 include those such as: no two aircraft occupy the same arrival time slot, others take  
29 into account the individual aircraft's performance capabilities (e.g., maximum  
30 speed/altitude, and fuel available).

1           In step 1105A, once a solution set of arrival times is generated, these changes  
2 are translated into a new set of trajectories and doable tasks or goals for each aircraft.  
3 One embodiment of the present invention calculates an arrival fix time or enroute  
4 speeds based on the new trajectories, as necessary, so as to meet the target arrival fix  
5 times for the aircraft.

6           In step 1106A, the initial targeted arrival fix times are communicated with an  
7 outside agency so that each operator of the present invention's request can be  
8 integrated into larger system goal.

9           In step 1107A, this new set of targeted arrival times or enroute speeds to meet  
10 the target arrival fix times is communicated to the pilots of the individual aircraft,  
11 which make up the set of interest. While as stated in the definitions, the arrival fix is  
12 a point some distance from the airport, in the future it can be moved closer to the  
13 airport, and can even be the landing point. This communication can be direct to the  
14 pilot through the ATC controller using voice or data link, or indirectly, through the  
15 airline/operator to the pilot. Additionally, this new set of targeted arrival times can be  
16 negotiated between the airline/operator and the CAA, where alterations can be made  
17 and sent back to the aviation authority for approval and re-optimization.

18           In FIG. 16 is seen an example of the coordination process so that each  
19 operator of the present invention's request can be integrated into larger system goal, if  
20 necessary. Here can be seen three operators of the present invention, all with their  
21 own initial target arrival fix times. By coordinating the operator's initial targeted  
22 arrival fix times through an independent agency (e.g., CAA), a more optimized  
23 system solution can be achieved. Absence this process, multiple operators of the  
24 present invention trying to better optimize the aircraft flow to the same arrival fix  
25 might assign an aircraft an arrival fix time, not realizing that another operator had  
26 also assigned that exact arrival fix time to one of their aircraft.

27           Even after these new targeted arrival times are established, the status of the  
28 various aircraft continues to be monitored, predictions continue to be made for their  
29 arrival fix times, and these continue to be compared to the solution set of targeted  
30 arrival fix times so as to quickly identify any newly developing conflicts. If such new

1 conflicts do develop, the process begins again and appropriate adjustments are made  
2 to the conflicted aircraft's targeted arrival fix times.

3 Thus, the present invention allows for the altering of the aircraft's landing  
4 times forward and backward in time so as to deliver the aircraft to a system resource  
5 (i.e., runway) in an orderly fashion. As in the just-in-time manufacturing processes,  
6 these aircraft must be delivered not too early, not too late, but right on time to  
7 maximize the throughput of the system resource.

8 The present invention's ways of optimizing an airport's operation differs from  
9 the current industry practices in several, important ways. First, the current gate hold  
10 process is often negated by the individual actions of the pilot through their various  
11 speed control measures once airborne. Additionally, since the typical "gate hold  
12 process" does not use all of the available, relevant data or is often implemented too  
13 far in advance, the value of such actions is lowered considerably and often leads to  
14 less than optimal aircraft flow. Second, since the arrival sequence is left to the  
15 controller near the airport or is set by the linear flow requirement of the current ATC  
16 system farther from the airport, it is either too late or too difficult to change the  
17 sequence by moving the sequence forward in time to allow for a more optimal flow of  
18 aircraft.

19 To further illustrate the present invention, consider the situation in which an  
20 airline/CAA is attempting to maximize the use of a runway – land the most aircraft in  
21 the least amount of time. Two parameters that effect runway usage are the  
22 consistency of the flow and sequencing of the arrival aircraft.

23 As discussed above, in the current art, the flow of aircraft is random and based  
24 on numerous independent decisions which lead to wasted runway capacity, excessive  
25 queuing times, and broad variances in aircraft arrival flow paths. See FIGS. 12, 17  
26 and 18. The present invention contributes to reducing wasted runway capacity by  
27 identifying and correcting potential arrival bunching or wasted capacity early,  
28 typically one to three hours (or more) before arrival. It does this as a result of having  
29 predicted the aircraft's trajectories, so that this flow can be spread both forward and  
30 backward so as to resolve the bunching. The decision as to which aircraft are moved  
31 forward or backward is based on numerous parameters, including the aircraft's speed

1 capabilities, the weather along the various flight trajectories, flight connection  
2 requirements, etc.

3 As also discussed above, the order of the aircraft, or their sequencing, as they  
4 approach the airport can also effect a runway's landing capacity. The present  
5 invention allows for the optimum sequencing of these aircraft so as to maximize a  
6 runway's landing capacity. See the bottom, arrival flow illustrated in FIG. 12.

7 In conjunction with the goal of efficiently managing the flow and sequencing  
8 of the aircraft to increase runway capacity, there are numerous other areas of the  
9 arrival process that can be optimized by the real time management of the  
10 arrival/departure flow of aircraft to an airport. These include: reduction of low  
11 altitude maneuvering, decreased length of the final approach leg, reduced fuel burn,  
12 on schedule arrival, decreased controller workload, maximum utilization of the  
13 runway asset, minimizing ramp/taxiway congestion, etc.

14 The first step is to determine the parameters/goals that the method is trying to  
15 optimize. While it is recognized that the present invention can manage and optimize  
16 many parameters simultaneously, for the purpose of describing how the system  
17 works, it proves instructive to consider a goal or goal function which is comprised of  
18 only a limited number of parameters. Consider the goal function comprised of the  
19 following parameters or elementary goals: (1) land an aircraft every minute, (2) have  
20 the incoming aircraft use a minimum amount of fuel, and (3) have the aircraft land on  
21 schedule.

22 To achieve the optimization of such a goal function, the present invention  
23 continuously determines the current position of all of the aircraft that are scheduled to  
24 arrive at a particular airport, or are enroute to that airport, say Atlanta (ATL). It does  
25 this by accessing ASD (providing aircraft current position and future flight intent),  
26 airline flight plans, or other position data, from numerous available sources. Using  
27 this current aircraft position data and stated future intent, the present invention builds  
28 a trajectory so that it establishes an estimated time that each of the aircraft will arrive  
29 at the runway (or arrival fix). These initial trajectories are built by the present  
30 invention without regard to what the controller will do, but built as if the aircraft is  
31 the only aircraft in the sky. In other words, these initial trajectories disregard the

1 actions that the controller must take, absence the present invention, to linearize the  
2 arrival flow of aircraft as they near the runway.

3 After the trajectories are built, the present invention must determine the  
4 accuracy of the trajectories. It is obvious that if the trajectories are very inaccurate,  
5 the quality of any solution based on these trajectories will be less than might be  
6 desired. The present invention determines the accuracy of the trajectories based on an  
7 internal predetermined set of rules and then assigns a Figure of Merit (FOM) to each  
8 trajectory. For example, if an aircraft is only minutes from landing, the accuracy of  
9 the estimated landing time is very high. There is simply too little time for any action  
10 that could alter the landing time significantly. Conversely, if the aircraft has filed its  
11 flight plan (intent), but has yet to depart Los Angeles for ATL there are many actions  
12 or events that would decrease the accuracy of the predicted arrival time.

13 It is easily understood that the FOM for these predictions is a function of time.  
14 The earlier in time the prediction is made, the less accurate the prediction will be and  
15 thus the lower it's FOM. The closer in time the aircraft is to landing, the higher the  
16 accuracy of the prediction, and therefore the higher it's FOM. Effectively, the FOM  
17 represents the confidence the present invention has in the accuracy of the predicted  
18 landing times. Along with time, other factors in determining the FOM includes  
19 validity of intent, availability of wind/weather data, availability of information from  
20 the pilot, etc.

21 Once the trajectories are built and their FOMs are determined high enough,  
22 the value of goal function is computed based on these predicted arrival times. Such a  
23 computation of the goal function often involves an algorithm that assigns a numerical  
24 value to each of its parameters based on the predicted arrival times. Often these  
25 parameters can be affected in contrasting ways by changing the predicted arrival  
26 times one way or another. For example, while it is an assumed goal to land an  
27 aircraft every minute, if the aircraft are not spaced properly, one solution is to speed  
28 up some of the aircraft, which requires more fuel to be used. Landing every minute is  
29 a plus, while burning extra fuel is a minus.

30 An example of how these goal function parameters might be defined is  
31 provided by considering the goal of landing one aircraft every minute. If the time

1 between the arriving aircraft is more or less than 1 minute, this parameter is assigned  
2 a number whereby numbers close to zero reflect closer attainment of the goal. For  
3 example, if an aircraft is one minute behind another aircraft, it is assigned a value of  
4 zero. If the distance is 2 minutes, it is assigned a value of 10. If the distance is 3  
5 minutes, its value is 100, and so on.

6 In the scenario in which we have an aircraft predicted to land at 12:15 (#1), no  
7 aircraft predicted to land at 12:16, 12:17, 12:18, or 12:19, and four aircraft (#2  
8 through #5) predicted to land at 12:20, we see that one has an opportunity to optimize  
9 that part of the goal function which is dependent on this parameter. A first potential  
10 solution for accomplishing this might be to move #2 to 12:16, #3 to 12:17, #4 to  
11 12:18 and #5 at 12:19. Yet to do this requires more fuel to be used by aircraft #2  
12 through #5. Further complicating this problem could be the fact that aircraft #4 is  
13 already 5 minutes late, while #2 is 4 minutes early, #3 is on time, while #5 is two  
14 minutes late.

15 If the goal function is defined simply as the sum of the parameters for the  
16 various aircraft whose operation and safety are sought to be optimized, we have what  
17 can be thought of as a linear process in which the goal function can be optimized by  
18 simply optimizing each aircraft's parameters. Alternatively, if we define our goal  
19 function to be a more complicated, or nonlinear, function so that we take into  
20 consideration how changes in one aircraft's predicted arrival time might necessitate a  
21 change in another aircraft's predicted arrival time, it is not as clear as to how to  
22 optimize the goal function. However, as is well known in the art, there exist many  
23 mathematical techniques for optimizing even very complicated goal functions.  
24 Meanwhile, it is recognized that such a nonlinear (i.e., optimize for the whole set of  
25 aircraft, airport assets, etc.) solution will often provide a better, safer and more  
26 efficient solution for the total operation of the airport, including all aspects of the  
27 arrival/departure flow.

28 To provide a better understanding how this goal function process'  
29 optimization routine may be performed, consider the following mathematical  
30 expression of a typical scheduling problem in which a number of aircraft, 1.....n, are



1 expected to arrive to a given point at time values  $t_1..t_n$ . They need to be rescheduled  
2 so that:

3 The time difference between two arrivals is not less than some minimum,  $\Delta$ ;

4 The arrival/departure times are modified as little as possible;

5 Some aircraft may be declared less "modifiable" than others.

6 We use  $d_i$  to denote the change (negative or positive) our rescheduling brings  
7 to  $t_i$ . We may define a goal function that measures how "good" (or rather "bad") our  
8 changes are for the whole aircraft pool as

$$9 \quad G_1 = \sum_i |d_i / r_i|^K$$

10 where  $r_i$  are application-defined coefficients, putting the "price" at changing  
11 each  $t_i$  (if we want to consider rescheduling the  $i$ -th aircraft "expensive", we assign it  
12 a small  $r_i$ , based, say, on safety, airport capacity, arrival/departure demand and other  
13 factors), thus effectively limiting its range of adjustment. The sum runs here through  
14 all values of  $i$ , and the exponent,  $K$ , can be tweaked to an agreeable value, somewhere  
15 between 1 and 3 (with 2 being a good choice to start experimenting with). The goal  
16 of the present invention is to minimize  $G_1$  as is clear herein below.

17 Next, we define the "price" for aircraft being spaced too close to each other.  
18 For the reasons, which are obvious further on, we would like to avoid a non-  
19 continuous step function, changing its value at  $\Delta$ . A fair continuous approximation  
20 may be, for example,

$$21 \quad G_2 = \sum_{ij} P((\Delta - |d_{ij}|)/h)$$

22 where the sum runs over all combinations of  $i$  and  $j$ ,  $h$  is some scale factor  
23 (defining the slope of the barrier around  $\Delta$ ), and  $P$  is the integral function of the  
24 Normal (Gaussian) distribution.  $d_{ij}$  stands here for the difference in time of  
25 arrival/departure between both aircraft, i.e.,  $(t_i + d_i) - (t_j + d_j)$ .

26 Thus, each term is 0 for  $|d_{ij}| >> \Delta + h$  and 1 for  $|d_{ij}| << \Delta - h$ , with a continuous  
27 transition in-between (the steepness of this transition is defined by the value of  $h$ ). As  
28 a matter of fact, the choice of  $P$  as the Normal distribution function is not a necessity;  
29 any function reaching (or approaching) 0 for arguments  $<< -1$  and approaching 1 for  
30 arguments  $>> +1$  would do; our choice here stems just from the familiarity.

A goal function, defining how "bad" our rescheduling (i.e., the choice of  $d$ ) is, may be expressed as the sum of  $G_1$  and  $G_2$ , being a function of  $d_1..d_n$ :

$$G(d_1..d_n) = K \sum_i C_i d_i^2 + \sum_{ij} P((\Delta - |d_{ij}|)/h)$$

with  $K$  being a coefficient defining the relative importance of both components. One may now use some general numerical technique to optimize this function, i.e., to find the set of values for which  $G$  reaches a minimum. The above goal function analysis is applicable to meet many, if not all, of the individual goals desired by an airline/aviation authority.

To illustrate this optimization process, it is instructive to consider the following goal function for  $n$  aircraft:

$$G(t_1...t_n) = G_1(t_1) + ... + G_n(t_n) + G_0(t_1...t_n)$$

where each  $G_i(t_i)$  shows the penalty imposed for the  $i$ -th aircraft arriving at time  $t_i$ , and  $G_0$  — the additional penalty for the combination of arrival times  $t_1...t_n$ . The latter may, for example, penalize when two aircraft take the same arrival slot.

In this simplified example we may define

$$G_i(t) = a \times (t - t_S)^2 + b \times (t - t_E)^2$$

so as to penalize an aircraft for deviating from its scheduled time,  $t_S$ , on one hand, and from its estimated (assuming current speed) arrival time,  $t_E$ , on the other.

Let us assume that for the #1 aircraft  $t_S=10$ ,  $t_E=15$ ,  $a=2$  and  $b=1$ . Then its goal function component computed according to the equation above, and as shown in FIG. 14, will be a square parabola with a minimum at  $t$  close to 12 (time can be expressed in any units, let us assume minutes). Thus, this is the "best" arrival time for that aircraft as described by its goal function and disregarding any other aircraft in the system.

With the same  $a$  and  $b$ , but with  $t_S=11$  and  $t_E=14$ , the #2 aircraft's goal function component looks quite similar: the comparison is shown in FIG. 14.

Now let us assume that the combination component, is set to 1000 if the absolute value  $(t_1 - t_2) < 1$  (both aircraft occupy the same slot), and to zero otherwise. FIG. 15 shows the goal function values for these two aircraft.

The minimum (best value) of the goal function is found at  $t_1=11$  and  $t_2=12$ , which is consistent with the common sense: both aircraft are competing for the  $t_2=12$

1 minute slot, but for the #1 aircraft, the  $t_i=11$  minute slot is almost as good. One's  
2 common sense would, however, be expected to fail if the number of involved aircraft  
3 exceeds three or five, while this optimization routine for such a defined goal function  
4 will always find the best goal function value.

5 Finally, to better illustrate the differences between the present invention and  
6 the prior means used for managing an airport's air traffic, consider the following  
7 examples:

8 Example 1 – When weather at an airport is expected to deteriorate to the point  
9 such that the rate of landings is lowered, the aviation authorities will “ground hold”  
10 aircraft at their departure points. Because of rapidly changing conditions and the  
11 difficulty of communicating to numerous aircraft that are being held on the ground, it  
12 happens that expected 1 to 2 hour delays change to 30 minute delays, and then to  
13 being cancelled altogether within a fifteen minute period. Also, because of various  
14 uncertainties, it may happen that by the time the aircraft arrives at its destination, the  
15 imposed constraint to the airport's landing rate is long since past and the aircraft is  
16 sped up for landing. An example of this scenario occurs when a rapidly moving  
17 thunderstorm which clears the airport hours before the aircraft is scheduled to land.

18 In an embodiment of the present invention, if an airport arrival rate is  
19 expected to deteriorate to the point such that the rate of landings is lowered, the  
20 present invention calculates arrival fix times for arriving aircraft based on a large set  
21 of parameters, including the predicted landing rate. The arrival fix times are  
22 communicated to the aircraft and the pilot departs and manages the flight path as  
23 necessary to meet the assigned arrival fix time. This allows the aircraft to fly a  
24 significantly more fuel-efficient speed and route. Additionally, this consistent flow of  
25 materials (aircraft) to the capacity limited airport/airspace is not only safer, but a  
26 consistent flow of materials is easier for the controllers to handle and therefore actual  
27 capacity is enhanced over the current, linear flow system.

28 Further, if the landing rate rises sooner than expected, the aircraft are already  
29 airborne, and therefore can react faster to new arrival fix times or enroute speed as  
30 necessary to meet the target arrival fix times to take full advantage of the available  
31 capacity

1           Example 2 - Numerous aviation delays are caused by the unavailability of an  
2 arrival gate or parking spot. Current airline/airport management techniques typically  
3 assign gates either too early (i.e., months in advance) and only make modifications  
4 after a problem develops, or too late (i.e., when the aircraft lands). In an embodiment  
5 of the present invention, gate availability, as provided by the airline/airport, is  
6 integrated into the arrival flow solution. By assigning the arrival fix times based on  
7 real time gate availability, more aircraft can be accommodated at the airport. This  
8 allows those aircraft with gates to land, and slows those aircraft without gates to a  
9 more fuel-efficient speed. Additionally, this helps minimize ground congestion,  
10 which can be significant at the larger airports like Chicago or Atlanta. For example,  
11 if an aircraft lands that does not have a gate available, it must be parked somewhere  
12 to wait for its gate and can, during this period, potentially impede the movement of  
13 departing aircraft, which further delays the arriving aircraft from getting to their  
14 gates. This creates a classic gridlock solution.

15           Example 3 – Given the increased predictability of the aircraft arrival/departure  
16 time, the process of the present invention helps the airlines/users/pilots to more  
17 efficiently sequence the ground support assets such as gates, fueling, maintenance,  
18 flight crews, etc.

19           Example 4 - Hub operations typically require a large number of actions to be  
20 accomplished by an airline in a very short period of time. One such group of events  
21 is hub landings and takeoffs. Typically in a tightly grouped hub operation, the  
22 departures of an airline's aircraft from the last hub operation compete for runway  
23 assets (a common asset) with the arrivals of the same airline for the next hub  
24 operation. It is one embodiment of the present invention to coordinate landing times  
25 with takeoff times for the aircraft, thus allowing the aviation authorities to minimize  
26 delays for access to the available runway for both takeoffs and landings or, with  
27 coordination with the airline/operator, allow delays to accrue to the aircraft that can  
28 best tolerate delays.

29           Example 5 – Embodied in the current art is the practice of rerouting aircraft  
30 around what is perceived as congested airspace. For example, the aviation authorities  
31 see a flight from Los Angeles to Philadelphia that is flight planned through what is

1 predicted to be a congested group of ATC sectors just east of Johnstown, PA. To  
2 alleviate this problem, prior to takeoff, the aviation authorities reroute the aircraft  
3 such that, instead of flying just south of Chicago, IL, the aircraft is on a more  
4 northerly route over Green Bay, WI, adding over 100 miles to the lateral path of the  
5 aircraft.

6 If this reroute is done as the aircraft approaches the runway for takeoff, often  
7 the case, not only does it add 12 to 13 minutes (the time necessary to fly the  
8 additional 100 miles) to the flight time, it delays the takeoff while the pilot analyzes  
9 the new route for fuel, weather, etc, as required by the aviation authorities. Once  
10 airborne, to mitigate this reroute, the pilot, assuming enough fuel, speeds up the  
11 aircraft to the point that the aircraft crosses over Johnstown on the longer route at the  
12 same time it would have on the shorter route based on the scheduled arrival time into  
13 Philadelphia.

14 The present invention can eliminate this type of rerouting. From prior to  
15 takeoff and throughout the flight, the present invention will continually analyze all of  
16 the airspace for potential congested areas. After sending an initial PHL arrival fix  
17 time, if the present invention continues to show the potential congestion over  
18 Johnstown at approximately one to three hours away from Johnstown, the aviation  
19 authorities now move to restrict the flow of aircraft through this airspace. The  
20 present invention does this by assigning crossing times at Johnstown for these aircraft  
21 that comprise the set of aircraft that are approaching Johnstown simultaneously which  
22 the aviation authorities have determined exceed capacity. Again, the focus of the  
23 present invention is to manage access to the problem, not limit access to the airspace  
24 system (i.e., ground holds at the departure airport) as is done in the current art. If the  
25 real time, time based sequencing of the present invention does not fully alleviate the  
26 congestion, the aviation authorities still have the option of rerouting some aircraft  
27 around the congested area as above.

28 Example 6 – The current thinking is that the airline delay/congestion problem  
29 arises from airline schedules that are routinely over airport capacity. The use of the  
30 present invention works to prevent real time capacity overloads by moving aircraft  
31 both forward and backward in time from a system perspective.

1           Take the example of the arrival flow at a typical hub airport as shown in FIG.  
2       13. During the day, the airport has eight arrival banks that are scheduled above the  
3       airport capacity. For example at 8:00 demand is below capacity, but by 8:30, the  
4       scheduled arrival demand exceeds capacity by 9 aircraft in good weather and 17  
5       aircraft in poor weather. And then by 9:00, demand is below capacity again.

6           It is one embodiment of the present invention to mitigate this actual over  
7       capacity in real time by moving aircraft forward in time into an area of less demand.  
8       By evaluating the set of aircraft leading up to and in the over capacity state, the  
9       present invention can assign earlier arrival fix times to those aircraft that have the  
10      ability to speed up. The present invention not only does this by moving over capacity  
11      aircraft forward in time, depending on the costs versus benefits. It may also move  
12      aircraft just prior to the over capacity period forward in time to accommodate more  
13      aircraft earlier.

14          Further, through coordination with the airline/operator, the airline/CAA can  
15      delay those aircraft that can best accommodate the delay (e.g., aircraft that are early  
16      or whose gate is not available until ten minutes after the potential landing time).

17          The solution to this example by the present invention can be viewed as  
18      clipping the top of a mountain. In the current art, the CAA solution is to move the top  
19      of the mountain above a certain altitude into the valley to the right of the mountain.  
20      Using the present invention, the offending mountain top (above the selected altitude)  
21      can be moved into the valleys left and right of the mountain top. While it is  
22      recognized that the movement of aircraft represent the core aviation process as  
23      described herein, the real time management of all of the aircraft is important to  
24      determining the most safe and efficient solution, for each given scenario.

25          The description of the management of the aircraft asset herein is also not  
26      meant to limit the scope of the patent. For example, the present invention will just as  
27      easily manage passengers as work-in-process assets, or gates, or food trucks, or pilots,  
28      etc., all of these, and other assets must be tactically managed to operate the aviation  
29      system in the most safe and efficient manner. Additionally, although the description  
30      of the current invention describes the time management of aircraft to an arrival fix, it  
31      just as easily manages departures or the flow of aircraft into or out of any system

1 resource. These system resources may include a small path through a long line of  
2 otherwise impenetrable thunderstorms, an ATC control sector that is overloaded, etc.

3 The foregoing description of the invention has been presented for purposes of  
4 illustration and description. Further, the description is not intended to limit the  
5 invention to the form disclosed herein. Consequently, variations and modifications  
6 commensurate with the above teachings, and combined with the skill or knowledge in  
7 the relevant art are within the scope of the present invention.

8 The preferred embodiments described herein are further intended to explain  
9 the best mode known of practicing the invention and to enable others skilled in the art  
10 to utilize the invention in various embodiments and with various modifications  
11 required by their particular applications or uses of the invention. It is intended that  
12 the appended claims be construed to include alternate embodiments to the extent  
13 permitted by the current art.

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